BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B69 09063

SUBJECT: Command Module Suit Heat Exchanger Computation of Heat Loads and Water Condensation - Case 620

DATE: September 25, 1969

FROM: D. P. Woodard

NASW-417

ABSTRACT

The command module suit heat exchanger removes heat from the suit and cabin atmospheres and transfers it to the water-glycol coolant circuit. As part of the cooling process, atmosphere humidity is controlled by vapor condensation. A mathematical model of the condensing, counterflow exchanger has been developed. Given coolant and gas inlet flow rates and temperatures, the computer program computes exit temperatures, sensible and latent heat loads, and water content of the exit gas.

The log mean temperature difference, overall heat transfer conductance method is used to characterize the heat exchanger. The analysis assumes saturated gas output operation and a constant total gas pressure across the exchanger. The specific heats of the gas and fluid are treated as functions of temperature.

Both CINDA and FORTRAN computer programs have been written and are operable; the results agree well with analyses reported by TRW.

(NASA-CR-107369) COMMAND MODULE SUIT HEAT EXCHANGER COMPUTATION OF HEAT LOADS AND WATER CONDENSATION (Bellcomm, Inc.) 15 p

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MEMORANDUM FOR FILE

INTRODUCTION

The following discussion describes a method of computing the heat transferred and the gas and fluid exit temperatures for a condensing, counterflow heat exchanger. Application to the Command-Module Suit Heat Exchanger gives results which agree well with analyses reported by TRW.*

The log mean temperature difference (LMTD), overall heat transfer conductance method is used to characterize the heat exchanger. The analysis assumes saturated gas output operation, and a constant total gas pressure across the exchanger. The specific heats of gas and fluid are treated as functions of temperature. Both CINDA and FORTRAN computer programs have been written and are operable.

DISCUSSION AND ASSUMPTIONS

The problem is illustrated schematically in Figure 1. Gas and coolant fluid enter the counterflow exchanger at temperatures TG5 and TF6 and exit at temperatures TG6 and TF5, respectively. Input flow rates, in lb/hr, are WF and WGV5 which is the sum of the gas constituent flow rates: oxygen, carbon dioxide, nitrogen, and water vapor. Unknowns are TG6, TF5, the several heat load components indicated in Figure 1, and the quantity of water removed by condensation. Operation of the exchanger is illustrated by the imaginary division into non-condensing and condensing parts. In the non-condensing part,transfer of sensible heat, Q1SENS, from the gas mixture to the fluid reduces the gas temperature to the dew point, TGDP. For the condensing part,further temperature reduction toward the exit temperature, TG6, results in condensation of water and the addition of both latent and sensible heat to the coolant fluid.** If the gas-vapor dew point is less than the gas exit temperature,i.e. TGDP $\leq$ TF6, no condensation can occur. For this case, the heat exchanger is treated as a non-condensing

*Apollo CSM ECS/Thermal Integrated Analysis Program, TRW Note No. 68-FMT-592, Revision 2, 13 January 1969.

**Refer to Table 1 for variable definitions.

exchanger; TG6 is very close to TF6, since the suit heat exchanger has a large overall transfer conductance. Consequently TG6 is set equal to TF6.

The following equations, which follow directly from the perfect gas relations, describe the gas side conditions: Given a mixture of gases having constituent weights W_i, molecular weights M_i, and specific heats CP_i, then the equivalent molecular weight of the mixture is:

$$(1) \quad M_{eq} = \frac{\sum_{i=1}^{n} W_i}{\sum_{i=1}^{n} \frac{W_i}{M_i}}$$

The equivalent specific heat of the mixture is:

$$(2) \quad CP_{eq} = \frac{\sum_{i=1}^{n} W_i \; CP_i}{\sum_{i=1}^{n} W_i}$$

The weight of water vapor, WH20, in a gas mixture at a total pressure of PT is related to the partial pressure of water, PH20, by

$$(3) \quad WH20 = \frac{18 \times WDG \times PH20}{WMDG\ (PT - PH20)}$$

where 18 is the molecular weight of water. The dependence of saturation partial pressure of water vapor on temperature is given by the usual "Steam Table" tabulations.

Oxygen and carbon dioxide specific heats are temperature dependent as given by

$$(4) \qquad CPO2 = .2188 + 1.222 \times 10^{-5} \cdot T \text{ Btu/lb°F}$$

$$(5) \qquad CPCO2 = .1940 + 1.778 \times 10^{-4} \cdot T \text{ Btu/lb°F}$$

The specific heats of nitrogen and water vapor are taken as constants, .250 and .450 Btu/lb°F, respectively. The enthalpy of water vapor is

$$(6) \qquad H = 1060 + .45 \cdot T \text{ Btu/lb.}$$

PROGRAM DESCRIPTION

Repeated use of Equations (1) through (6) permit the iterative computation of the desired heat loads and exit temperatures as shown by the program flow chart, Figure 2. Required input data are gas constituent flow rates (WO25, WCO25, etc), inlet temperatures (TG5 and TF6), total gas pressure (PT5), and steam table data (saturated water vapor partial pressure vs. temperature). These data yield molecular weights (WMDG5, WMGV5), total flow rates (WDG5, WGV5), specific heats (CPDG5, CPGV5), input enthalpy (H5), and dew point temperature (TGDP).

For the non condensing case, TGDP $\leq$ TF6. TG6 is set equal to TF6 because of the large overall heat transfer conductance. In this case the heat load is all sensible and given by the products of (TG5 - TF6), the average gas-vapor specific heat ($CPGVAV = \frac{CPGV5 + CPGV6}{2}$) and the flow rate, WGV5.

For the condensing case, TGDP > TF6. Successive assumptions: TG6 = TF6 + .5, TG6 = TF6 + 1., and TG6 = TF6 + 5. are used to determine if

$$(TF6 + .5) \leq TG6 \leq (TF6 + 5.)$$

or if

$$(TF6 + 1.) \leq TG6 \leq (TF6 + 5.)$$

Linear interpolation is used to determine subsequent approximations to TG6 until the conductance difference |HEQ - HTOT| is less than .5. The terms are defined by the equations:

$$(7) \quad HEQ = Q1SENS/LMTD1 + Q2/LMTD2,$$

$$(8) \quad LMTD1 = \frac{(TG5 - TF5) - (TGDP - TFDP)}{\ln \dfrac{(TG5 - TF5)}{(TGDP - TFDP)}},$$

$$(9) \quad LMTD2 = \frac{(TGDP - TFDP) - (TG6 - TF6)}{\ln \dfrac{(TGDP - TFDP)}{(TG6 - TF6)}},$$

$$(10) \quad HTOT = (HGAS) \cdot (HFLUID)/(HGAS + HFLUID),$$

$$(11) \quad HGAS = 99.09\ (WGVEQ)^{.27716},$$

$$(12) \quad HFLUID = 86.52\ (WF)^{.40248},$$

$$(13) \quad WGVEQ = \frac{(WGV5 + WGV6)\ (H5 - H6)}{(TG5 - TG6)(CPGV6 + CPGV5)}$$

As the water content of the entering gas, WH205, decreases and TGDP approaches TF6, the condition can be reached where

$$TF6 \leq TG6 \leq TF6 + .5.$$

In this case the convergence of HEQ to HTOT is tested using successive approximations to TG6 of TF6 + .5, TF6 + .25, TF6 + .125, and TF6 + .0625. If |HEQ - HTOT| is still not less than .5, TG6 = TF6 is assumed to be sufficient since

$$TF6 \leq TG6 \leq TF6 + .0625.$$

PROGRAM RESULTS

Table 2 compares the results of two cases input to this program and analyzed by TRW. Agreement is good. Differences in QLAT, and QTOTAL are due to the assumption of a constant total pressure which has the effect of shifting the dew point,TGDP, slightly. TRW's program balances the pressure drops and rises around the gas circuit and does not assume a constant pressure system.

Table 3 shows the effect of decreasing the amount of water, WH2O5, in the input gas mixture for Case 1. The number of iterations required to obtain a solution for each run is also included in the tabulation. Note that runs 1 through 4 proceeded normally with condensation and a steadily decreasing QLAT. Run 5 resulted in a marginal removal of QLAT; 4 iterations and a resultant TG6 = TF6 = 45.23°F indicate that four attempts were made to define TG6 between the limits 45.23 and 45.73. The dew point temperature, TGDP, for runs 6 through 10 is less than TF6 = 45.23°F; as a result no condensation occurred, TG6 was set equal to TF6, and no iterations were required.

D P Woodard

D. P. Woodard

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Attachments

TABLE 1

PROGRAM VARIABLES

W025	=	oxygen flow rate, lb/hr
WC025	=	carbon dioxide flow rate
WN25	=	nitrogen flow rate
WH205	=	water vapor flow rate
WF	=	fluid flow rate
TG5	=	gas-vapor inlet temperature, °F
TF6	=	fluid inlet temperature
PT5	=	gas inlet total pressure, PSIA
WDG5	=	inlet dry gas flow rate, lb/hr
WGV5	=	inlet gas-vapor flow rate, lb/hr
WMDG5	=	inlet molecular weight of dry gas, lb/mol
WMGV5	=	inlet molecular weight of gas-vapor, lb/mol
V5	=	inlet volumetric flow rate, ft^2/hr
CPDG5	=	inlet specific heat of dry gas, BTU/lb °F
CPGV5	=	inlet specific heat of gas-vapor
H5	=	inlet gas-vapor enthalpy, BTU/lb dry gas
PH205	=	inlet vapor partial pressure, PSIA
TGDP	=	inlet gas-vapor dew point temperature
CPDGDP	=	specific heat of dry gas at TGDP
CPGVDP	=	specific heat of gas vapor at TGDP
CPGVAV	=	average specific heat of gas-vapor across non-condensing portion of HX
Q1SENS	=	sensible heat removed by the non-condensing portion of HX
TG6	=	exit gas-vapor temperature
TF6	=	exit fluid temperature
PH206	=	exit vapor partial pressure, PSIA
WH206	=	exit vapor flow rate, lb/hr
WGV6	=	exit gas-vapor flow rate, lb/hr
CPDG6	=	exit specific heat of dry gas
CPGV6	=	exit specific heat of gas vapor
H6	=	exit gas-vapor enthalpy, BTU/lb dry gas
QTOTAL	=	total heat exchanger heat load, BTU/hr
WGVEQ	=	equivalent gas-vapor flow rate across total heat exchanger, lb/hr
HGAS	=	overall gas side transfer conductance of heat exchanger, BTU/°F
HFLUID	=	overall fluid side transfer conductance
HTOT	=	overall heat exchanger transfer conductance
Q2	=	total heat removed by the condensing portion of the heat exchanger, BTU/hr
CPF6	=	fluid inlet specific heat
TFDP	=	fluid temperature at TGDP
CPFDP	=	fluid specific heat at TFDP
TF5	=	fluid exit temperature

TABLE 1 (continued)

LMTD1	=	log-mean-temperature difference across non-condensing portion of HX, °F
LMTD2	=	log-mean-temperature difference across condensing portion of HX, °F
HEQ1	=	equivalent transfer conductance of non-condensing portion of HX
HEQ2	=	equivalent transfer conductance of condensing portion of HX
HEQ	=	overall equivalent transfer conductance of HX, (HEQ = HEQ1 + HEQ2)
TG61	=	first estimate of gas-vapor exit temperature
DELH1	=	first overall transfer conductance difference
TG62	=	second estimate of gas-vapor exit temperature
DELH2	=	second overall transfer conductance difference
Q2SENS	=	sensible portion of Q2
QSENST	=	total sensible heat load
QLAT	=	latent heat load

TABLE 2

SUIT HEAT EXCHANGER PROGRAM RESULTS COMPARED TO TRW ANALYSES

VARIABLE	UNITS	CASE 1		CASE 2	
		SHX Program	TRW	SHX Program	TRW
WO25	lb/hr	53.836	-	54.606	-
WCO25	lb/hr	.982	-	.996	-
WN25	lb/hr	0.000	-	0.000	-
WH2O5	lb/hr	1.619	-	1.580	-
WF	lb/hr	200.	-	208.0	-
TG5	°F	120.05	-	109.713	-
TF5	°F	45.23	-	45.23	-
QSENST	BTU/hr	922.19	922.22	804.29	801.13
QLAT	BTU/hr	684.74	716.6	634.20	656.48
QTQTAL	BTU/hr	1606.93	1638.82	1438.49	1457.61
TG6	°F	46.75	46.50	46.53	46.75
TF5	°F	56.45	56.60	54.89	54.96
TGDP	°F	59.32	61.81	58.25	56.95
WGV5	lb/hr	56.44	-	57.18	-
WGV6	lb/hr	55.82	55.76	56.61	56.56

TABLE 3

EFFECT OF INLET GAS WATER CONTENT ON SHX HEAT LOADS AND TEMPERATURES

Input Conditions:

WO25	=	53.836 lb/hr	TG5	=	120.04	gas inlet T
WCO25	=	.982	TF6	=	45.23	fluid inlet T
WN25	=	0.0	WF	=	200.	
WH2O5	=	variable	PT5	=	5 psia (constant)	

Run	WH2O5 lb/hr	QTOTAL BTU/hr	QSENS BTU/hr	QLAT BTU/hr	TGDP °F	TG6 °F	TF5 °F	Iterations
1	1.619	1606.9	922.2	684.7	59.32	46.75	56.45	7
2	1.580	1568.2	922.7	645.6	58.64	46.67	56.18	7
3	1.40	1390.3	924.7	465.6	55.48	46.26	54.94	5
4	1.20	1190.1	926.3	263.9	51.40	45.86	53.55	7
5	1.0	998.7	930.0	68.7	46.68	45.23	52.22	4
6	.80	924.5	924.5	0	41.04	45.23	51.71	0
7	.70	921.6	921.6	0	37.75	45.23	51.69	0
8	.65	920.1	920.1	0	35.93	45.23	51.68	0
9	.60	918.6	918.6	0	33.97	45.23	51.67	0
10	.55	917.1	917.1	0	32.00	45.23	51.66	0

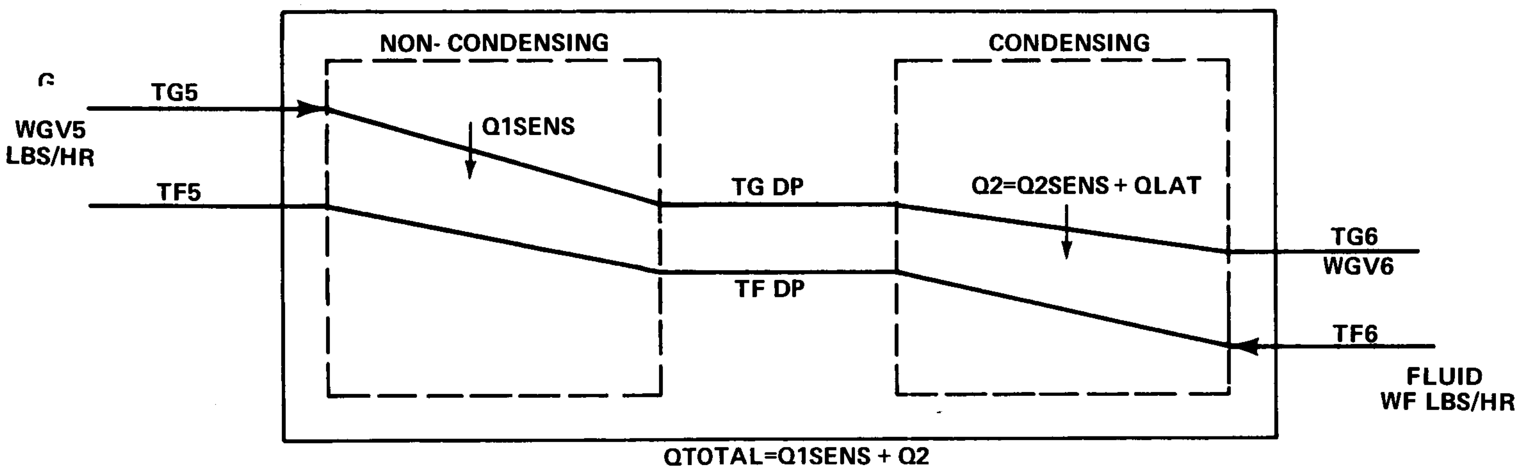
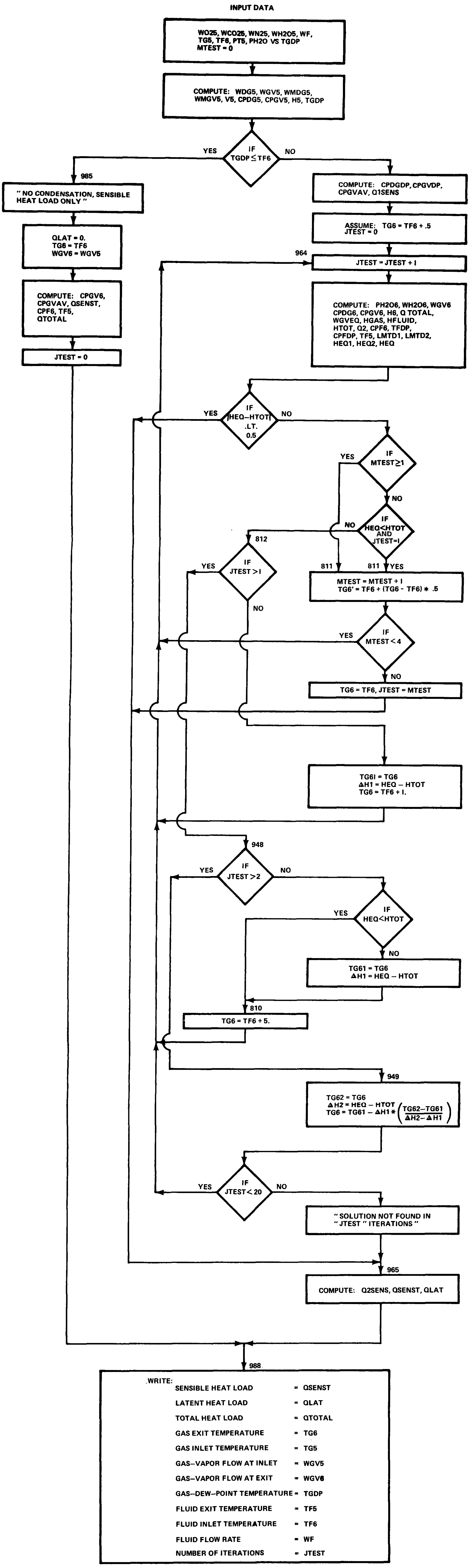


FIGURE 1- SUIT HEAT EXCHANGER



COMMAND MODULE SUIT HEAT EXCHANGER FLOW CHART

FIGURE 2

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From: D. P. Woodard

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